Water and nitrogen use efficiency of forage kale crops

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Abstract

Water and nitrogen (N) availability can limit forage kale (*Brassica oleracea* ssp. *acephala* L.) production. There are quantitative data on N uptake and its partitioning, but limited data on water use and no data on the combined effects of water and N on growth of forage kale crops in New Zealand. 'Regal' kale crops were grown in a rain-out shelter at Lincoln, Canterbury under eight treatments: a factorial combination of four N rates (0, 30, 120, 240 kg/ha) with either full irrigation or no rain or irrigation over summer, hereinafter referred to as summer drought. Final dry matter (DM) yield increased with both water and N supply, from 7.2 t DM/ha for the 0 kg N/ha plots to 10.7 t DM/ha for the plots receiving 240 kg N/ha under the summer drought treatments and from 15.2 t DM/ha to 18.1 t DM/ha for the same N treatments, respectively, with full irrigation. Apparent water use for forage kale increased with water application, from 263 mm for the summer drought treatments to 537 mm for the fully irrigated treatments but was unaffected by N application. Water use efficiency (WUE) increased with N application from 35.3 kg DM/ha/mm for treatments receiving ≤ 30 kg N/ha to 40.6 kg DM/ha/mm for those receiving ≥ 120 kg N/ha. However, WUE was unaffected by water application, with a mean of 38 kg DM/ha/mm. Total N uptake increased with both water and N application; from 180 kg/ha under summer drought treatments to 220 kg/ha for the fully irrigated treatments and from ≤ 165 kg/ha when ≤ 30 kg N/ha was applied to ≥ 220 kg/ha when ≥120 kg N/ha. Moreover, the applied N use efficiency (ANUE) increased from 6.4 g DM/g N/m^2 for the irrigated plots to 19.2 g DM/g N/m^2 for the summer drought plots but was unaffected by N application. However, the ANUE traits; applied N uptake efficiency and utilisation efficiency did not respond to the water and N treatments, with mean values of 38% and 50 g DM/g N/m^2, respectively.

Additional keywords: *Brassica oleracea* ssp. *acephala,* applied N uptake efficiency, applied N use efficiency, applied N utilisation efficiency, drought, neutron probe tubes, potential yield, time domain reflectometry, water use efficiency

Introduction

Forage brassica crops occupy the largest area of cultivated land in New Zealand, with over 300 000 hectares grown annually (Dumbleton *et al.* 2012). There are quantitative data on dry matter (DM) yield, nitrogen (N) uptake and its partitioning, and the nutritive quality for forage kale (*Brassica oleracea* ssp. *acephala* L.) crops (Nichol *et al*., 2003; Wilson and Maley, 2006; Wilson *et al*., 2006; Chakwizira *et al*., 2009; Fletcher *et al*., 2010). However, data on water use and the combined effects of water and N on growth of forage kale crops in New Zealand are limited. Forage kale crops are widely grown as a source of high-quality feed for winter (Chakwizira *et al*., 2012). Their cultivation covers a wide range of soil fertility and climatic environments (Wilson *et al*., 2006) and hence these variables are often major contributors to variation between fields and seasons (Wilson *et al*., 2006; Chakwizira *et al*., 2009, 2012). Well-grown kale crops can produce 20-25 t DM/ha (Brown *et al*., 2006; Fletcher *et al*., 2007) compared with ≤ 6 t DM/ha for N-stressed, dry-land grown crops (Wilson *et al*., 2006; Chakwizira *et al*., 2009).

The availability of sufficient soil water often limits forage brassica crop DM yields (Fletcher *et al*., 2010). This limitation can be expressed as the product of total water use (WU; mm) and the efficiency with which water is used (WUE; kg DM/ha/mm) by these crops. Fletcher *et al*. (2010) have reported WUE of 32.3 kg DM/ha/mm for forage rape and 34.1 kg DM/ha/mm for forage turnips. Jacobs *et al*. (2004) reported WUEs of 6-45 kg DM/ha/mm for forage turnips, while Neilsen *et al*. (2000) found WUE ranged from 15 to 38 kg DM/ha/mm for four forage brassicas with clear differences between species. Although there is limited published WU and WUE data for forage brassica crops for New Zealand conditions; Martin *et al*. (2006) have identified 20 kg DM/ha/mm water as an appropriate benchmark for irrigated dairy pastures for Canterbury region of New Zealand. Moot *et al*. (2008) reported WUEs for a range of pastures in New Zealand, ranging from 7 to 40 kg DM/ha/mm water; with the high WUE attributed to the application of sufficient N. This is consistent with the results of Jacobs *et al*, (2004) for forage turnips. However, Fletcher *et al*. (2010) found that neither water treatments nor N application affected WUE for kale crops. It is therefore unclear whether forage kale WUE is unresponsive to water and N supply as reported by Fletcher *et al*. (2010) or increases with additional N as reported for other crop species e.g. turnips (Jacobs *et al*., 2004) and pastures (Moot *et al*., 2008).

Studies on effects of water and N on forage brassica crops such as kale have been prompted by the need to establish accurate irrigation and N recommendations for optimum production, thus avoiding potential yield penalties due to undersupply, or environmental pollution due to oversupply of these key resources. This in turn has led to the development of Forage Brassica Calculators (Wilson *et al*., 2006; Chakwizira *et al*., 2011, 2012). Even though recent research has highlighted the need for appropriate water and N application, the effect of these stresses combined has been, surprisingly, little investigated in forage brassica crops such as kale.

The objectives of this experiment were to determine water and N and their combined effects on DM yield, N uptake and use efficiency, and water use and use efficiency for kale crops.

Materials and Methods

The experiment was conducted in a mobile rain-out shelter (Martin *et al*., 1990) at The New Zealand Institute for Plant & Food Research Limited, Lincoln (43° 49' 48" S, 171° 43' 12" E), New Zealand. The rain-out shelter automatically excludes rainfall from the experimental site, enabling soil water availability to be closely controlled by differential irrigation treatments. The soil at the site is a deep (>1.6 m) and well drained Templeton sandy loam (*Udic Ustochrep*, UDA Soil Taxonomy) (Jamieson *et al*., 1995), with an available water-holding capacity of approximately 190 mm/m depth. Physical characteristics of the soils are described by Martin *et al*. (1992).

The experiment used a randomised complete block design, consisting of eight treatments: a factorial combination of two rates of irrigation (full irrigation, or no rain or irrigation over summer, hereinafter referred to as summer drought) and four rates of N (0, 30, 120, 240 kg/ha), replicated three times. The experiment was sown into a cultivated seed bed on 14 November 2011 using a Taege drill with an Oyjord cone seeder. 'Regal' kale seed was sown at 4.1 kg/ha into 150 mm spaced rows. The site had been under a perennial ryegrass (*Lolium perenne* L.) crop for the previous 3 years. Plot size was 3.6 m × 5.0 m, with 1.0 m between plots.

The site was prepared by deep ploughing followed by power harrowing. Twenty soil samples to a depth of 150 mm were randomly taken from the experimental area on 29 April 2011, evenly mixed, and a representative 100 g sample taken for analyses. Average soil test results were as follows: pH 6.0, Olsen P 16, potassium (K) 100, calcium (Ca) 1250, magnesium (Mg) 55, sodium (Na) 25 mg/kg soil and available mineral N 60 kg/ha. The amounts of soil nutrients were determined as 'MAF quick-test units' (Mountier *et al*., 1966) and converted into mg/kg dry soil using the following conversion factors: Ca, x125; K, x20; Mg, Na, x5; P, x1.1 (Chapman and Bannister, 1994). Basal fertilisers were applied at 240 kg/ha triple superphosphate (20.5% P), 100 kg/ha potassium chloride (52% K and 48% Cl) and 15 kg/ha boronate (10% B). These were broadcast and incorporated into the soil before sowing. Nitrogen treatments were split applied in three equal amounts for each treatment, at 33, 59 and 80 days after sowing (DAS), through irrigation with 4.8, 4.2 and 5.1 mm, respectively.

Herbicides, fungicides and pesticides were applied to the crop (Table 1) when needed so that crop yield was not compromised. There was severe leaf damage after application of the fungicide. This was suspected to be spray damage, and may have been due to the chemical being sprayed during midday on a hot day. Although the damage covered the whole experiment, it was more pronounced on the irrigated treatments.

After sowing, irrigation was managed in common across the site until 20 December 2011 (37 DAS). A drip irrigation system was subsequently installed and the two irrigation treatments were established. After the crop damage by the fungicide, a decision was made to apply water to all the plots from 3 April 2012 (142 DAS) to the final harvest. Initially, all plots were irrigated with 15 mm water on 3 April 2012 and an additional 35 mm to the summer drought plots the following day. Equal amounts of water were then applied to all plots thereafter, based on time domain reflectometry (TDR) readings. A total of 489.3 mm and 145.3 mm of water was applied to the irrigated and summer drought crops, respectively, throughout the growing season.

Table 1: Herbicides, fungicides and pesticides applied during establishment and crop growth period to the kale crops grown under different water and nitrogen rates at Lincoln, Canterbury in the 2011-12 season.

Chemical	Trade name	Active ingredient (a.i.)	Application rate (volume/ha)	Date applied
Herbicide	Treflan®	400 g/l trifluralin (EC)	2.0 l	9 November 2011
	Banvel®	200 g/l dicamba (SC)	800 ml	16 December 2011
				18 January 2012
Fungicide	Dithane®	800 g/kg mancozeb (WP)	2 kg	29 March 2012
Insecticide	Di Grub™	800 g/l diazinon (EC)	350 ml	9 November 2011
				16 November 2011
			1.0 l	16 December 2011
				26 December 2011
				18 January 2012
				22 March 2012
	Perfekthion®	500 g/l dimethoate (EC)	800 ml	3 February 2012
	Lorsban®	750 g/kg chlorpyrifos (EC)	1.2 l	17 February 2012

Measurements

Neutron probe (NP) access tubes and TDR wave guides were installed for the duration of the experiment in each plot following seedling emergence. Measurements of volumetric soil water content were made for each plot at weekly intervals beginning on 14 December 2011 (31 DAS). Measurements were made in increments of 200 mm to a depth of 1600 mm. The 0-200 mm depth was measured using TDR, while all other measurements were made using NP.

Apparent crop water use (WU) was calculated by the difference in volumetric soil water content between the current day and the start of the experimental measurements, plus any inputs from irrigation. When WU and crop biomass measurements were on different days, WU was estimated by linear interpolation between two subsequent measurements. The potential water extraction patterns were determined for crops exposed to the most severe water stress only, up to 3 April 2012; as irrigation confounds interpretation of the water extraction patterns (Fletcher et *al.*, 2010). Water use efficiency (WUE) was calculated as described by Fletcher et *al.* (2010). Briefly, linear regression of the sequential crop biomass measurements were plotted against the WU and the gradient of the slope was the WUE. The WUE for the kale crops was calculated for both irrigation treatments through-out the growing season.

Measurements of crop biomass were made at 66, 106, 138 and 190 DAS. Four rows of crop, each measuring 2 m in length, giving a total of 1.2 m^2, were cut from each plot. At the final harvest 18 rows of crops, each measuring 1 m in length (total area of 2.7 m^2) were harvested. Plant density and total fresh weight per harvest per plot were determined in the field. A five-plant sub-sample was taken from each plot harvest and separated into leaf, petiole and stem fractions. Fresh weights for the partitions were determined before drying in a fan-forced oven at 60°C until constant weight.

For each plot harvest, about 30 g each of biomass were finely ground with a Cyclone

Sample Mill (Udy Corporation, Fort Collins, Colorado, USA) to pass through a 1 mm sieve for N determination by a combustion technique using a LECO-200CN auto analyser (LECO Corporation, St Joseph, MI, USA) and expressed on a dry matter basis. Nitrogen concentrations (%), yields (kg/ha) and efficiencies (g/g/m^2; %) were then computed using the basic data measured in the field or laboratory as follows (Baligar *et al.* 2001; Sinebo *et al.* 2004):

Leaf N yield (LNY) = leaf N concentration (LNC) × leaf DM yield (1)

Stem N yield (SNY) = stem N concentration (SNC) × stem DM yield (2)

Total biomass N yield (TNY) = leaf and stem yields combined (3)

$$\text{Applied N use efficiency}\left(\text{ANUE; }\left(\frac{\text{g}}{\text{g}}\text{m}^2\right)\right) = \frac{\text{BYf} - \text{BYo}}{\text{Nf}} \qquad (4)$$

where: BYf = the biomass yield with fertiliser N
BYo = the corresponding biomass yield without fertiliser application for the same water treatment and replication
Nf = the rate of fertiliser N applied.

Applied nitrogen uptake efficiency (ANupE), also called applied N recovery efficiency, was calculated as:

$$\text{ANupE (\%)} = (\text{TNYf} - \text{TNYo})\ \text{x}\ \frac{100}{\text{Nf}} \qquad (5)$$

where: TNYf = the total biomass N yield with application of fertiliser N
TNYo = the corresponding total biomass N yield without fertiliser application for the same water treatment and replicate.

Applied N utilisation efficiency (ANutE) was obtained as:

$$\text{ANutE} = \frac{\text{BYf} - \text{BYo}}{\text{TNYf} - \text{TNYo}} \qquad (6)$$

Data analyses

The DM yields and yield components, N uptake and use efficiencies and WU and WUE were analysed using multivariate analysis of variance (MANOVA) for repeated measures and analysis of variance (ANOVA) for single measurements. Significant interactions and main effects were separated using Fisher's protected least significant difference (LSD) tests (α=0.05). Where values show P<0.1, a trend is indicated in the text. Sum of squares were also used to explain variations in the measured attributes.

Results

At the final harvest, kale DM yield from the irrigated plots (16.1 t DM/ha) was 76.3% greater ($P<0.001$) than from the summer drought plots (Figure 1). Dry matter yield also increased ($P<0.003$) in response to N application, although the extent of the response to N was less than the response to water treatments. For instance, under water treatments the application of 240 kg N/ha increased yield by 19.3% to 18.1 t DM/ha for the irrigated plots and 48.6% to 10.7 t DM/ha for the summer drought plots compared with their respective control N treatments. The DM yield differences ($P=0.016$) due to N supply observed for the summer drought crops occurred after irrigation was applied to these plots (Arrow A; Figure 1).

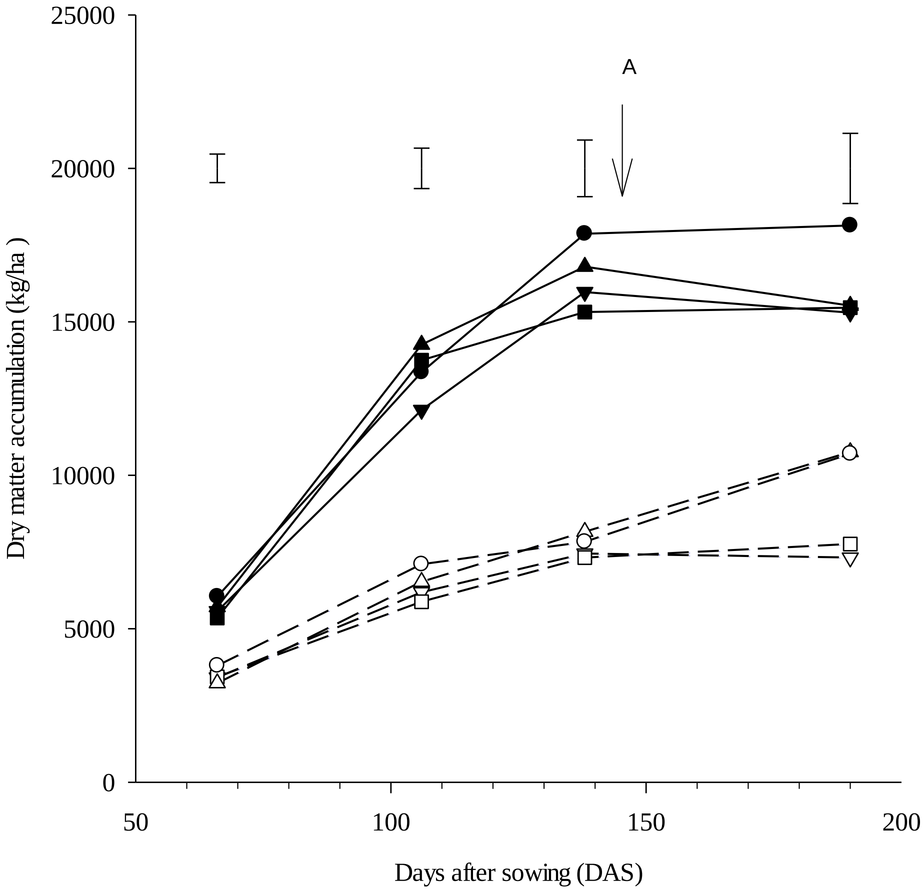

Figure 1: Dry matter accumulation for kale crops grown under two water regimes: full irrigation where water was applied weekly to a total of 489.3 mm (solid symbols), and summer drought plots which were fully irrigated from 3 April 2011 (142 DAS; Arrow A) to a total of 145 mm (open symbols) and four rates of nitrogen: 0 kg N/ha (▼▽), 30 kg N/ha (■□), 120 kg N/ha (▲Δ) and 240 kg N/ha (●○), at Lincoln, Canterbury, New Zealand in the 2011-12 season. Bars represent the least significant differences ($LSD_{0.05}$; 14 d.f.). Arrow A indicates the point at which water was applied to all the summer drought plots across the trial.

The potential water extraction for kale crops was shown for plots exposed to summer drought (Figure 2a) averaged across N treatments, as WU was unaffected (P=0.86) by N application. The crops were extracting most of their water to a depth of about 1100 mm at mid-season (14 February) and 900-1500 mm at the end of the season (3 April 2012). From about mid-season to the end of the season, water extraction was negligible in the top 300 mm depth. The total WU increased (P<0.001) with water application, from 263 mm for the summer drought plots to 537 mm for the fully irrigated plots.

Forage kale WUE increased with N application, from 35.3 kg DM/ha/mm for the plots receiving ≤ 30 kg N/ha to 40.6 kg DM/ha/mm for the plots receiving ≥ 120 kg N/ha (Figure 2b). However, WUE was unaffected (P=0.12) by water treatments, with a mean value of 38 kg DM/ha/mm through the season. There were no differences in WUE between the control N treatments and those receiving 30 kg N/ha and also between the higher rates of N.

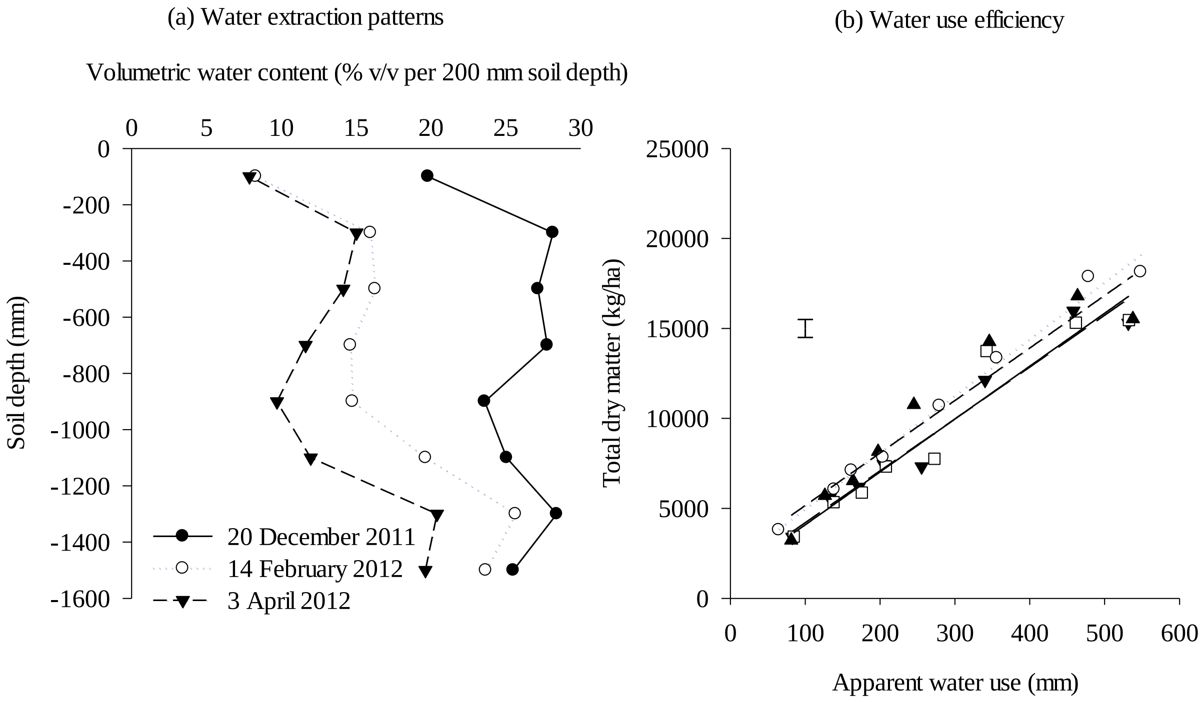

Figure 2: (a) Mean water extraction pattern for kale crops grown under summer drought treatments (no N effect) for three dates representing early season (20 December), mid-season (14 February) and late season (3 April) and (b) the relationship between dry matter yield and apparent water use for kale crops grown under different N rates: 0 kg N/ha (▼), 30 kg N/ha (□), 120 kg N/ha (▲) and 240 kg N/ha (○). The gradient of the regression lines represent the water use efficiency: Y=35.3x + 1233 (R^2=0.94) for ≤ 30 kg N/ha treatments, Y=39.6x + 2240 (R^2=0.92) for 120 kg N/ha treatments and Y=41.7x + 1812 (R^2=0.98) for 240 kg N/ha treatments.

At the final harvest, combined water and N stresses did not affect any of the measured variables (Table 2) except for the SNC ($P<0.05$). Specifically, SNC increased with N application for summer drought plots from 1.2% for the plots receiving ≤ 120 kg N/ha to 1.9% for the 240 kg N/ha plots, and was unaffected by N application for the irrigated plots. Overall N concentration was greater ($P<0.001$) in the leaves, at 3.5% of DM, compared with the 1.2% for the stems.

Water treatments affected the LNC, SNC, SNY, TNY and ANUE (Table 2), while the N treatments affected LNY, SNC, SNY and TNY, as reflected by the large sums of squares for the respective attributes for each treatment. The LNC was greater ($P=0.03$) in summer drought plots, at 3.7%, compared with the 3.4% for the irrigated plots. A similar trend was also observed for the SNC, at 1.4% and 1.0%, respectively. Nitrogen supply increased SNC ($P=0.013$) from 1.0% for the control N plots to 1.4% for the 240 kg N/ha plots. Subsequently, SNY increased ($P<0.001$) with N application from 86.5 kg/ha for the control N plots to 148.6 kg/ha for the 240 kg N/ha plots. Both SNY and TNY were greater ($P<0.001$) in the irrigated plots, at 133.2 kg N/ha and 219.3 kg N/ha, respectively, compared with 97.3 and 179.4 kg N/ha for the summer drought plots. The ANUE increased ($P<0.08$; Table 2) from 6.4 for the irrigated plots to 19.2 for the summer drought plots. Neither water nor N ($P\geq0.13$; Table 2) affected ANupE and ANutE, with mean values of 38% and 50 g/g/m^2, respectively.

There was an interaction ($P=0.007$; Figure 3) between water and N treatments over time on TNY. Specifically, irrigated plots had consistently higher TNY across the N treatments than summer drought plots up to 142 DAS, but there were no differences between the water treatments for the 120 and 240 kg N/ha plots at 190 DAS. However, the control and 30 kg N/ha plots had lower TNY for the summer drought plots throughout the season. The TNY was on average double in irrigated plots compared with the summer drought plots, across the N treatments (Figure 3). However, at the final harvest (190 DAS) there were no differences in TNY between the water treatments for the 120 and 240 kg N/ha.

Table 2: Levels of significance of variance sources and their relative contributions to the total sum of squares for nitrogen concentrations, nitrogen uptake (yield) and efficiency traits for kale crops grown under water and nitrogen limitations at Lincoln, Canterbury in 2011-12 season. These data are for the final harvest.

Variance	d.f.	Level of significance[1]								Sum of squares (% of total)							
source		LNC	LNY	SNC	SNY	*t*NY	ANUE	ANupE	ANutE	LNC	LNY	SNC	SNY	*t*NY	ANUE	ANupE	ANutE
W	1	*	NS	***	***	**	*	NS	NS	18.6	1.1	27.4	26.2	15.2	21.0	0.9	13.0
N	3	NS	**	**	***	***	NS	NS	NS	20.3	50.2	24.1	54.0	58.1	2.3	11.0	4.0
W x N	3	NS	NS	*	NS	NS	NS	NS	NS	7.2	8.5	16.6	5.1	6.0	13.6	9.9	24.2

[1]NS = non-significant, *, **, *** = significant at 0.05, 0.01, 0.001 respectively.

LNC=leaf N concentration, LNY=leaf N yield, SNC=stem N concentration, SNY=stem N yield, *t*NY = total biomass N yield, ANUE=applied N use efficiency, ANupE=applied N uptake efficiency and ANutE=applied N utilisation efficiency.

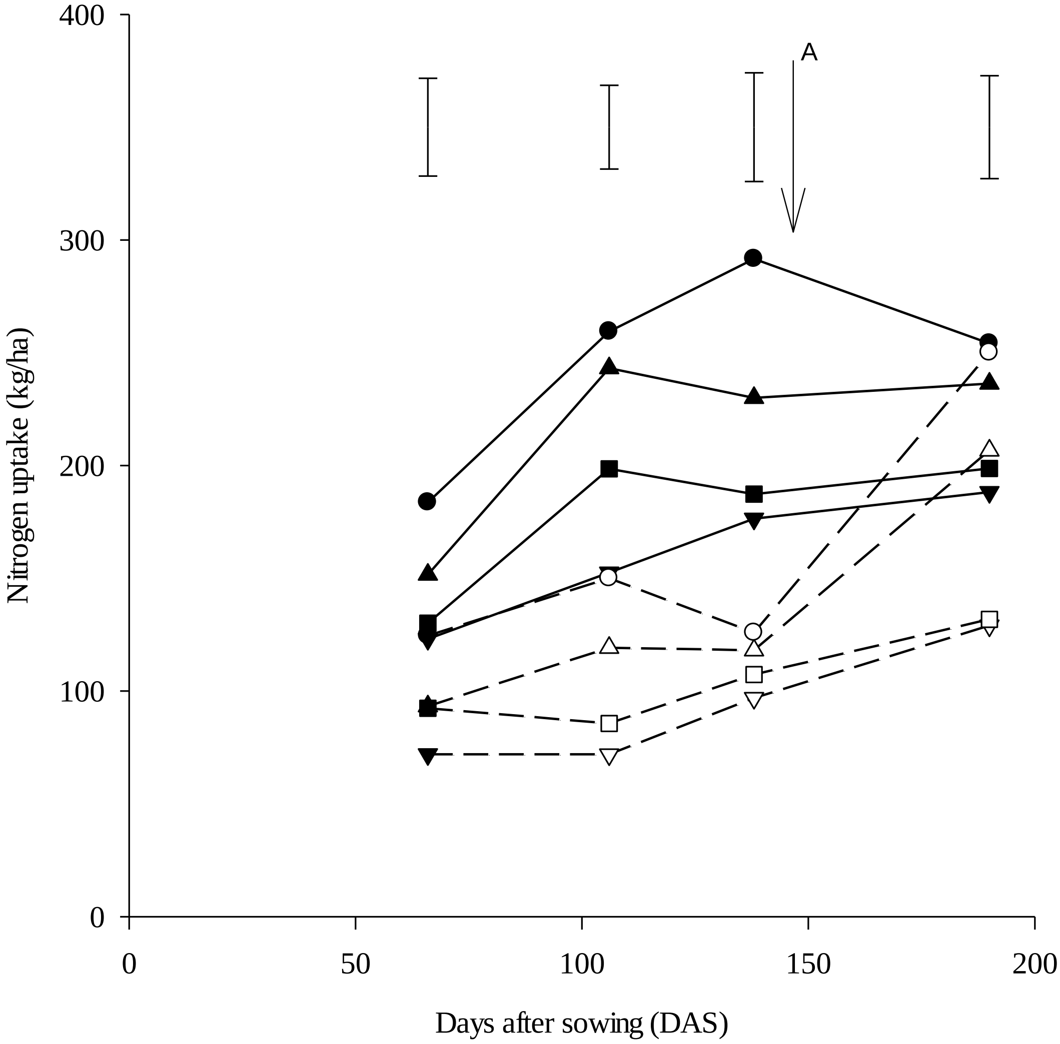

Figure 3: Total nitrogen uptake for kale crops grown under two water regimes: full irrigation, where water was applied weekly to a total of 489.3 mm (solid symbols), and summer drought plots which were fully irrigated from 3 April 2011 (142 DAS; Arrow A) to a total of 145 mm (open symbols) and four rates of nitrogen: 0 kg N/ha (▼▽), 30 kg N/ha (■□), 120 kg N/ha (▲∆) and 240 kg N/ha (●○), at Lincoln, Canterbury, New Zealand in the 2011-12 season. Bars represent the least significant differences ($LSD_{0.05}$; 14 d.f.). Arrow A indicates the point at which water was applied to all the summer drought plots across the trial.

Discussion

The results show the importance of both water and N in the DM production of forage kale (Figure 1). However the extent of the response to N was not as pronounced as those to water; highlighting the importance of water in crop production. The WU doubled with full irrigation to 537 mm, compared with the summer drought crops. This accounted for the DM yield differences between the water treatments of

76.3%. As the total DM yield for forage kale crops are a product of the WU and WUE (Fletcher *et al.*, 2010) and in the current experiment only WU responded to the water treatment: it is recommended that farmers growing forage kale crops determine the total amount of water available to the crop through-out the season. This can be estimated using knowledge of the initial soil moisture, soil depth (and water holding capacity; WHC) and long term average (LTA) rainfall for that particular area. This knowledge of the total available soil water in any particular region, combined with the established WUE can be used to estimate the potential yield for forage kale crops and to determine whether there is need to irrigate crops, as a way to increase the potential yield. For example, a rain fed kale crop grown at Lincoln, Canterbury, on a deep Templeton sandy loam soils with an available WHC of 190 mm/mm of depth at field capacity, receiving about 330 mm of rainfall between sowing (November) and start of grazing (June) (LTA; NIWA, 2013) and with about 50 mm of soil evaporation will yield about 14.3 t DM/ha (Equation 7). Moreover, irrigating the same crops, say with 150 mm of water through-out the season will increase the DM yield to 20 t DM/ha (Equation 8).

$$\text{DM yield} = ((0.5 \times \text{WHC}) + (\text{rainfall - evaporation})) \times \text{WUE} \qquad (7)$$

$$\text{DM yield} = ((0.5 \times \text{WHC}) + (\text{rainfall - evaporation}) + \text{irrigation})) \times \text{WUE} \qquad (8)$$

Equation 8 shows how irrigation can be used to increase DM yield in forage kale crops, by making more water available for extraction. However, most of the irrigated forage kale crops are grown in Canterbury, which accounts for 20% of the kale production in New Zealand (White *et al*., 1999). This implies that more than 80% of the forage kale crops grown in New Zealand are dry-land produced and therefore can benefit from maximising WU (Fletcher et al., 2010). This can be achieved through maximising rooting depth and therefore, soil water available to the crops and also the use of fallow periods before forage kale crops are sown to ensure soil profiles are at /or near field capacity (Passioura and Angus, 2010). As the WUE increased with N application (Figure 2b); N can be used strategically with irrigation to increase the overall yield for forage kale crops. Using the examples above, the irrigated forage kale crops (Equation 8) grown with ≥120 kg N/ha (WUE = 40.6 kg DM/ha/mm) will yield 3 t DM/ha more at 21.5 t DM/ha compared with those receiving ≤ 30 kg N/ha (WUE = 35.3 kg DM/ha/mm). The increase of WUE with N supply has been reported for other species, such as pastures (Moot *et al*., 2008) and forage turnips (Jacobs *et al*., 2004). However, in Fletcher *et al*. (2010) WUE did not respond to N application, which could be attributed to the high initial available mineral N of 96 kg/ha in their experiment compared to the 60 kg/ha in the current experiment; which meant N did not limit growth of forage kale even when low rates of N where applied.

The DM yields in the current experiment (Figure 1) are consistent with those reported for the Canterbury region of 6-13 t DM/ha for dry-land kale production (Wilson *et al*., 2006; Chakwizira *et al*.,

2009) and 14-19 t/ha for irrigated kale crops (Wilson *et al*., 2006). These DM yields demonstrated the importance of irrigating forage kale crops in dry environments and the strategic use of N for enhancing the overall DM yields. Low DM yield under water stress have been reported for other forage brassica crops such as forage rape and bulb turnips (Chakwizira and Fletcher, 2012). This was attributed to limited leaf expansion and hence reduced radiation interception.

The DM yield for the summer drought, high N treatments increased rapidly after the introduction of irrigation (Arrow A: Figure 1). This was attributed to the increased availability of water and hence ability of the crops to take up either the fertiliser N and/or soil N that was in the soil under summer drought conditions. Under water stress, crop may stop taking up N (Gonzalez-Dugo *et al*., 2010) because of (*i*) a cessation or reduction in transpiration or (*ii*) having used the entire N amount in the larger soil pores, leaving only that which is in the small soil pores, which they cannot extract. In the latter case, irrigation restored the transpiration stream and/or refilled the larger pores leading to movement of N into the smaller soil and the resultant higher N uptake (Figure 3). The increased N uptake after droughts has also been attributed to the stimulation of soil microbial activity and mineralisation of soil organic N due to the availability of moisture (Wright and Davison, 1964). However, this may be unlikely in the current experiment, as the final N uptake (Figure 3) reflected the N application patterns and background soil N. This suggests that the additional N uptake was from the N that was already in the soil, either from the fertiliser N applied or from background soil N content.

The tissue concentration of N was higher in the leaves than stems. This is consistent with results reported by Jones (1959) and Cornforth *et al.* (1978). However, the SNY ranges in the current experiment were lower than the 1.5-2.4% reported by those authors. This could be attributable to cultivar differences. Higher total N uptake (Figure 3) is consistent with results reported by Wilson and Maley (2006) and Fletcher *et al.* (2007). These were attributed to the kale crops' high demand for N and their extensive root systems and its ability to take up N from a larger soil volume. Wilson *et al.* (2006) have also reported that kale crops are inefficient at taking up N from the soil compared with other crops, e.g. maize (Barbieri *et al*., 2008) and low land rice (Baligar *et al*., 2001). This was confirmed by the low ANupE of 38% in the current experiment. The implications of the low ANupE are that large amounts of applied fertiliser N that remain in the soil are exposed to leaching.

Conclusions

Results show that water availability impacted forage kale growth more than N. As WUE was similar for the water treatments but increased with N; farmers can use their knowledge of soil water holding capacities (storage) and rainfall patterns on their properties to estimate potential DM yield, with no irrigation. This, coupled with strategic N application and irrigation where available, can be use to enhance forage kale DM production. The overall DM yields demonstrated the importance of irrigation in forage kale production in dry environments. Farmers can apply high rates of N under irrigation and no or low N in dry seasons; however the actual rates of N application should be base on initial soil tests and potential yield for the area.

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